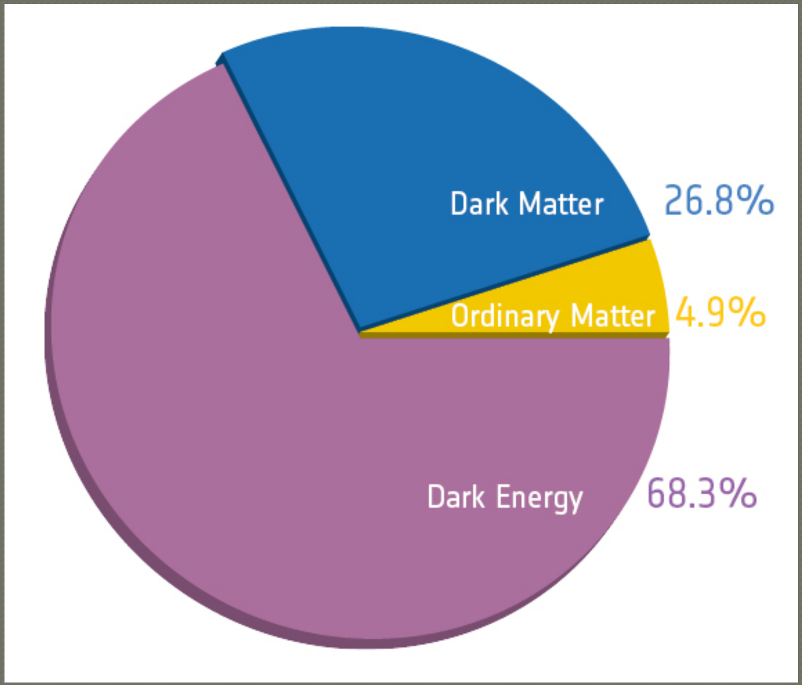
a comprehensive map of galaxy & black hole evolution over cosmic time

Leonidas Moustakas
JPL/Caltech

The luminous universe

- cosmic components



Planck Collaboration 2013

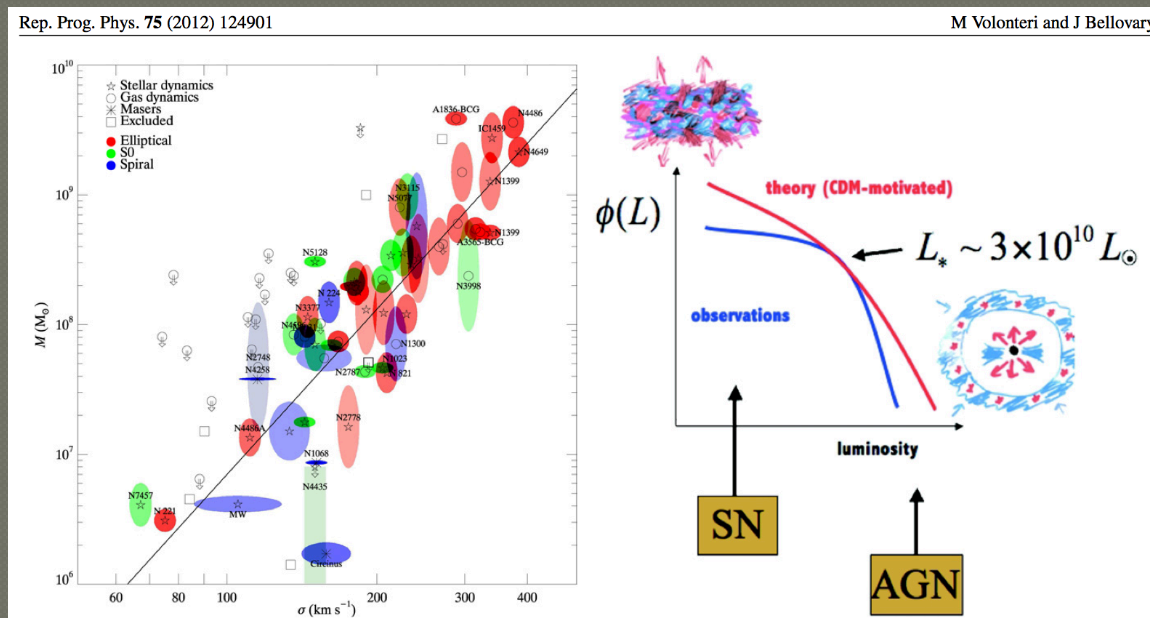
- The ~5% *ordinary matter* component (and the consequent collapsed objects) produce the luminous universe we observe.

Star Formation & Black Holes

- Star formation (SF) processes produce energy through nuclear fusion, and thermal & non-thermal radiation.
- The immediate and extended volumes near black holes (BH) produce energy through gravitational accretion, enabled by MHD processes, and energy transfer affects both local and "global" galactic environments.
- All galaxies appear to host massive BHs in their cores, which are active at times, likely through mechanisms connected to galaxy evolution.

Co-evolution of BHs & galaxies…

Black hole mass in ***local*** galaxy centers



Luminosity functions, and relation to mass function

Galaxy velocity dispersion = proxy for mass

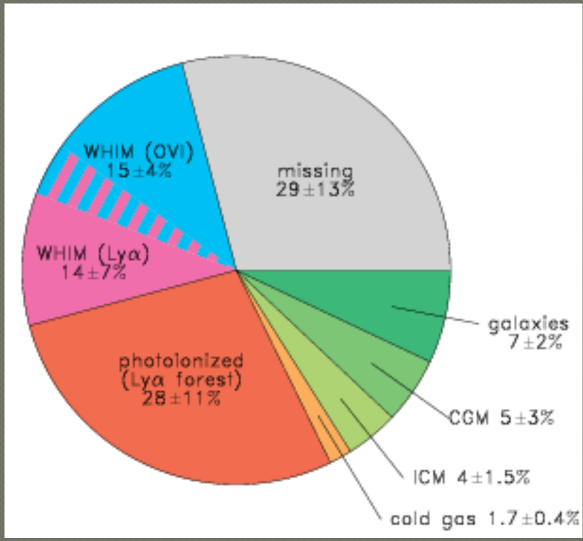
- There is clearly a co-evolutionary connection between galaxies and their central black holes, whether active or quiescent.
- Activity in black holes plays a key role in regulating star formation in galaxies above a specific mass scale.
- We have begun to characterize this; a deep understanding of it is of the future.

The ultimate goal

- There is an interrelation of baryonic and black hole formation and evolution processes.
- These communicate with each other, or have common physical / astrophysical triggers.
- To achieve a deep understanding of these connections observationally and in fundamental theory, we are driven to assemble a set of experiments that inform key elements of the problem, from the very local to extreme reaches of cosmic time.

Vignettes on the theme. I.

- A full census of baryonic components and structure
  - The 'missing' media: probing warm/hot gas around galaxies: Ultraviolet (to soft X-ray) spectroscopy, to go beyond the neutral components
  - Structure of stellar distributions: strong gravitational lensing observations



Shull+2012, ApJ,759,23

Moustakas+ 2013

Vignettes on the theme. II

- Chemical and 6D phase space structure, over cosmic time
  - Stellar: spectroscopically determined abundances of GAIA volume
    - Chemical tagging for ages, metallicities, and abundance ratios, towards inferring formation and assembly history.
  - Black hole masses and structure: reverberation mapping
    - Time domain precision spectroscopy; could leverage strong lenses.
  - Thermal signatures for both stellar and active components: mid-infrared all-sky mapping, "WISE at $z>1+$"
    - Mid-infrared full sky imaging survey to AB=16

Vignettes on the theme. III.

- Pushing the limits:
  - Expanding "near" field cosmology to great distances: high resolution optical/UV.
  - Expanding "near" baryonic process mapping to even greater distances: galaxy-IGM interactions into the re-ionization era(s).

Enabling the science. I.

- Apertures and telescopes
  - Lightweight mirrors (silicon carbide casting and figuring), phased with laser truss to diffraction-limiting tolerances
    - Enables capabilities at both small (SMEX) and large (20+ meter) apertures, over the full span of the roadmap exercise.
    - Actuator control and segmented panel assembly presently being tested at JPL and elsewhere.

Enabling the science. II.

- Detectors
  - High quantum efficiency ultraviolet detectors
    - Delta-doping techniques
  - Microwave Kinetic Inductance Detector (MKID)
    - Photon energy & time tagging over large fields of view
    - Coverage ~ 0.2-1.8um, spectroscopic R~50 => magnitude limits of ~30 in 20ksec at SNR>10 in each wavelength bin.
    - Can be used as a high-spec resolution splitter/sorter
    - See Ben Mazin talk on 5/7/13.

Enabling the science. III.

- Instruments
  - Integral field spectroscopy
    - Mapping the internal kinematic structure of individual galaxies at high sensitivity, to z>2: R>several thousand…
    - At each technological stage, map the galaxy / local mediums characteristics and interactions, from local to z~8: R>tens of thousands…
    - Complementarity of densely packed IFS fields, and wide-field, programmable highly multiplexing masks
      - Cobra mechanism, microshutters, etc
      - Another option: tie-in with photon-tagging detectors (MKIDs) that track positional information as well.

Enabling the science. IV.

- Programmatics: Mission Implementation.
  - Large solid angle vs targeted
    - Complementarity in mission design
  - Time domain programs for time-variable phenomena
    - Strongly lensed multiply-imaged accreting black holes
    - Reverberation mapping
      - The relevant time-scales increase with black hole mass (because of crossing times), and redshift ($x(1+z)$).

Enabling the science. V.

- Computational resources and theoretical advances
  - Including baryonic processes
    - This remains a massive challenge for the foreseeable future.
  - Trillion particle simulations
    - For reference: the Bolshoi dark matter-only cosmological simulation has just a few x billion particles tagged and traced
  - Inference and analysis techniques
  - Quantum computing
    - Alternative computational techniques

The next three decades

Way-station	*Scientific Challenges*		*Technological Challenges*
	Wide-field	Targeted	
By the 2020s	* "Missing baryon" mapping through UV integral field spec/y.	* Dynamics and chemistry of "in the act" black hole activity caught by LSST. * Percent precision mass maps of galaxy structure with redshift, leveraging strong gravitational lensing.	* High QE FUV detectors. * >1 arcmin IFS. * Several thousand multiplex, >1deg field spec capability. * Sub-percent reproducible time domain spectrophotometry.
By the 2030s	* Precise stellar RV and chemical measurements of *all* stars within the GAIA volume. * Mid-infrared AB=16 full-sky imaging survey	* Reverberation mapping tomography of "emerging" black holes at onset of activity from quiescence.	* Trillion-particle galaxy simulations including baryonic processes. * Kinetic Inductance detector photon tagging over large fields of view.
By the 2040s	"Near-field cosmology" from resolved stars in distant galaxies.	* Galaxy-IGM interactions at z>8. * Identify and dynamically measure masses of quiescent black holes to Dark Ages threshold.	* Quantum computing for rapid inference theoretical interpretations of observations. * SNR>10, R>20,000 spectra of quasars. * SNR>100, R>10,000 spectra of stars in distant galaxies.

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- Several technological and programmatic themes connect this science goal:
  - A distributed but deliberately coordinated effort from Explorer through Flagship scale missions
    - This can be enabled through new light and assembled apertures
  - Spectroscopy (multiplexing and integral) is important
    - Chemical, kinematic, dynamic mapping from stars through high redshift galaxies and accreting black holes
  - Optimized time domain mission implementation
    - Time variability in active galaxies, particularly modulated through strong gravitational lenses, has great promise across broad mission scales
  - The theoretical underpinnings *must* be addressed in parallel, both for forecasting and mission design, and for interpretation.